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MOTOR VEHICLE EXHAUST EMISSIONS—

GARY, INDIANA

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If this pollution were distributed over the 41.6 square miles that comprise the land area of the City of Gary, the emission density for these two pollutants would be 63.5 pounds per square mile as compared to the emission density for carbon monoxide of 845.9 pounds per square mile. The vehicle-mile average-speed approach is presently the most accurate method for estimating the emissions from motor vehicle exhausts. The total emission of sulfur oxides and particulates from motor vehicles is small as compared with the three major pollutants. The use of the emission factors based on the fixed-mode cycle does not, therefore, introduce much error in the total weight of pollutants.

MOTOR VEHICLE EXHAUST EMISSIONS—

GARY, INDIANA

A study done by the Abatement and Control Programs,
National Center for Air Pollution Control, for
Division of Air Pollution, City of Gary, Indiana.

by

C. R. Rehmann

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of Disease Prevention and Environmental Control
National Center for Air Pollution Control
Durham, North Carolina
1968

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MOTOR VEHICLE EXHAUST EMISSIONS – GARY, INDIANA

INTRODUCTION

At the request of the Division of Air Pollution of the City of Gary, Indiana, the Abatement and Control Programs of the National Center for Air Pollution Control conducted an emissions inventory of the major pollutants from motor vehicle exhausts. This request was made to supplement more general information that was included in an emissions inventory of the major pollutants from all sources in the Northwest Indiana area.

Motor vehicles emit pollutants in varying quantities and chemical composition. This report is concerned with the pollutants generally found in urban environments: carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulates.

The major source of pollution from motor vehicles is the exhaust system. Intensive testing has been completed on exhaust emissions, and the emission rates based on a vehicle operating under a fixed-mode cycle have given way to emission rates based on the actual operating cycle of the engine. The emission rates that were based on the fixed-mode cycle did not include the stresses applied to the operation of a vehicle's engine by the actual driving cycle. Rose, et al.[1] developed a relationship for emission rates and average trip speed that includes the effects on emissions produced by variations in route, traffic density, speed, etc. These rates, when applied to comprehensive traffic information, should produce an accurate emissions inventory.

The sources of emissions from motor vehicles are not limited to exhaust emissions. Evaporative losses from the fuel tank, the carburetor "hot-soak" and the crankcase are the other locations of major emissions from motor vehicles. These locations are of such a nature as to emit only hydrocarbons in

detectable quantities. Since evaporative and crankcase losses occur in the stationary position and during the operating cycle, the emissions are distributed in a different fashion from the exhaust emissions. The location of these emissions, as they are vented to the atmosphere, is related to the location of the vehicle, the climatology of the area, the operating mode of the vehicle, and various other factors that make it difficult to locate on a firm basis the evaporative and crankcase losses; therefore, they are considered only briefly in this report.

The vehicle-mile average-speed approach is used in this report to estimate the emissions from motor vehicles. This approach is based upon emission rates developed by testing the exhaust emissions under the actual driving cycle. The method depends entirely on the type of traffic information available, such as vehicle counts, traffic flow maps, and speed studies. National averages can be incorporated to complete the information needed in making a comprehensive estimate of traffic conditions of the study area.

The vehicle-mile average-speed approach is used primarily to estimate carbon monoxide and hydrocarbon emissions, which, according to National Averages, comprise more than 95 percent of the total weight of pollution from motor vehicles. This approach also is used to estimate nitrogen oxide emissions; however, this pollutant does not vary specifically with speed, but is dependent upon the air-fuel ratio. In this report an average air-fuel ratio of 12.8* was used.

The exhaust emissions of sulfur oxide and particulates were included by utilizing factors based on the fixed-mode cycle of operation since curves have not been developed on the operating cycle basis. Automobile exhausts do contribute significant amounts of particulates in urban areas as the result of secondary reactions; therefore, they are included even though the fixed-mode based factors have to be used.

The following sections summarize the results of this inventory and outline the procedure followed in this report. An outline of a procedure for completing or updating a motor-vehicle exhaust emission survey is also included.

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*This average air-fuel ratio is the result of extensive tests on motor vehicles conducted in Los Angeles, Denver, and Cincinnati by the Public Health Service.

SUMMARY

The results of the motor-vehicle exhaust emission inventory are reported by a grid system on a map of the study area and by grids in the Appendix of this report. Figures 1, 2, and 3 illustrate the distribution of the three major pollutants throughout the City of Gary.

The total amounts of pollutants emitted from motor vehicle exhausts are listed in Table 1.

Table 1. EMISSIONS FROM MOTOR VEHICLES IN GARY, INDIANA

Units	Type of pollutants				
	Carbon monoxide	Hydrocarbons	Nitrogen oxides	Sulfur oxides	Particulates
lb/day	351,850	26,630	11,950	1,190	1,450
lb/year	128.4×10^6	9.72×10^6	4.36×10^6	0.43×10^6	0.53×10^6
tons/year	64,200	4,860	2,180	215	265
Percent of total weight of pollutants	89.50	6.78	3.04	0.31	0.37

Evaporative losses and crankcase emissions in the study area account for 47 percent of the total hydrocarbon emissions, and exhaust emissions compose the remaining 53 percent. Typical analysis of motor vehicle emissions, conducted by the U. S. Public Health Service,[2] was used to check these estimates. This report shows that 51 percent of the hydrocarbon emissions are from crankcase and evaporative losses, and that 49 percent of the emissions are vented from the exhaust. The differences in this report are due to utilizing national averages to complete the local traffic information.

Three pollutants - carbon monoxide, hydrocarbons, and nitrogen oxides - comprise 99 percent of the total weight of exhaust emissions in the study area. Sulfur oxides and particulates generally compose the greater percentage of the pollution in an industrial-urbanized area; however, these pollutants comprise only a small portion of the total weight of exhaust emissions. These pollutants are significant because of their toxicity, particle size, and secondary reactions involving the formation of aerosols.

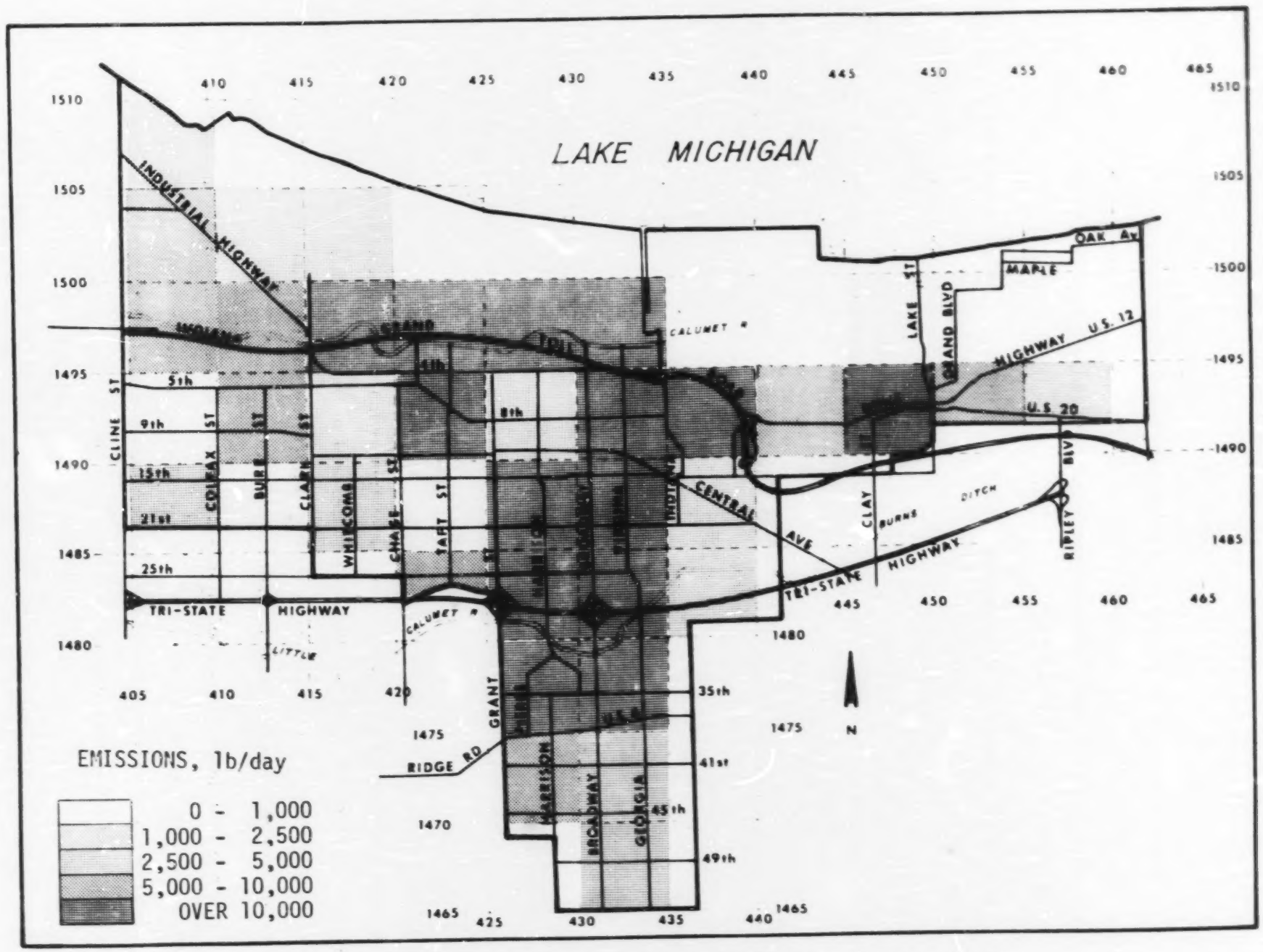

Figure 1. Vehicle carbon monoxide emissions in Gary, Indiana.

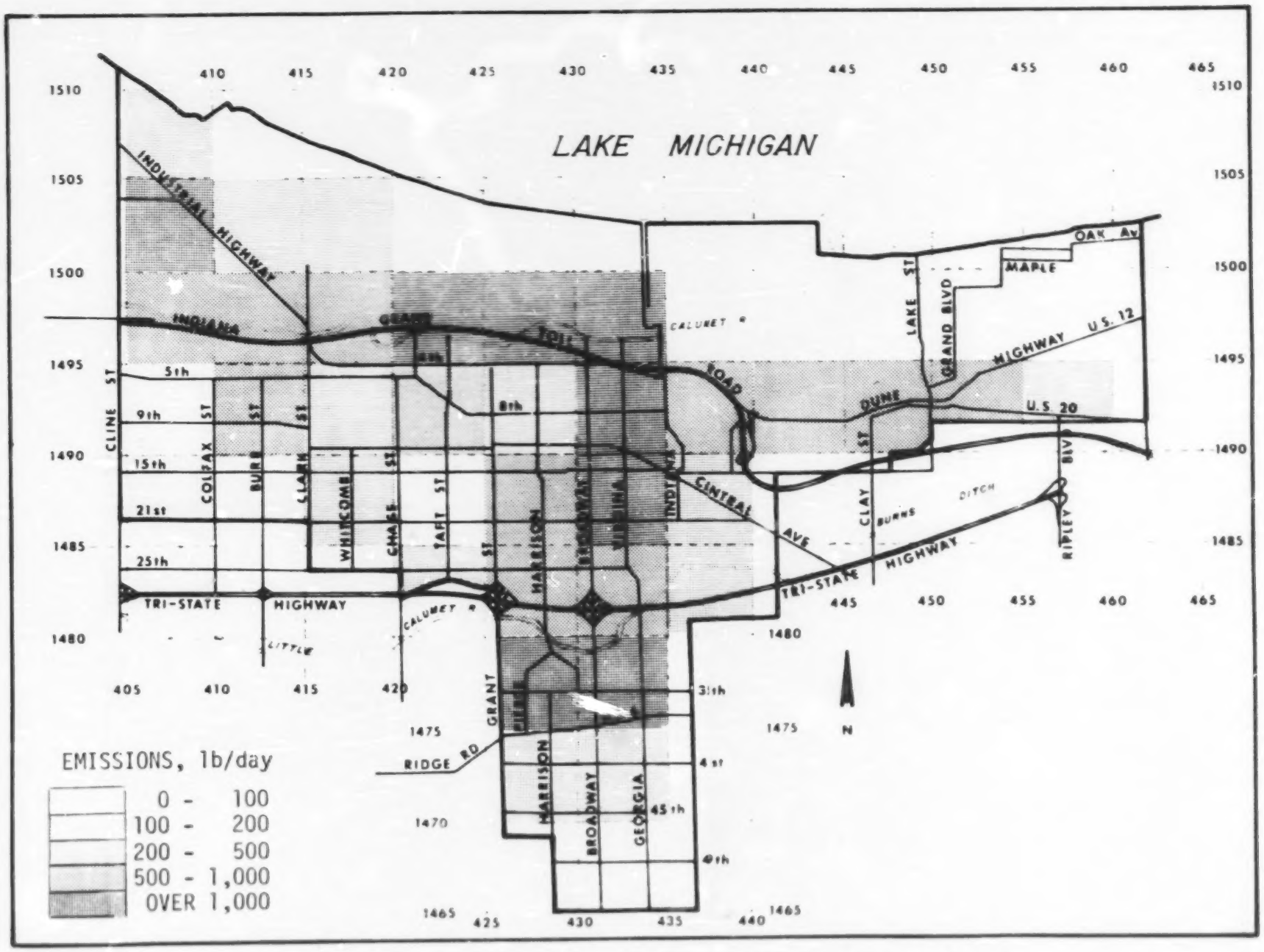

Figure 2. Vehicle hydrocarbon emssions in Gary, Indiana.

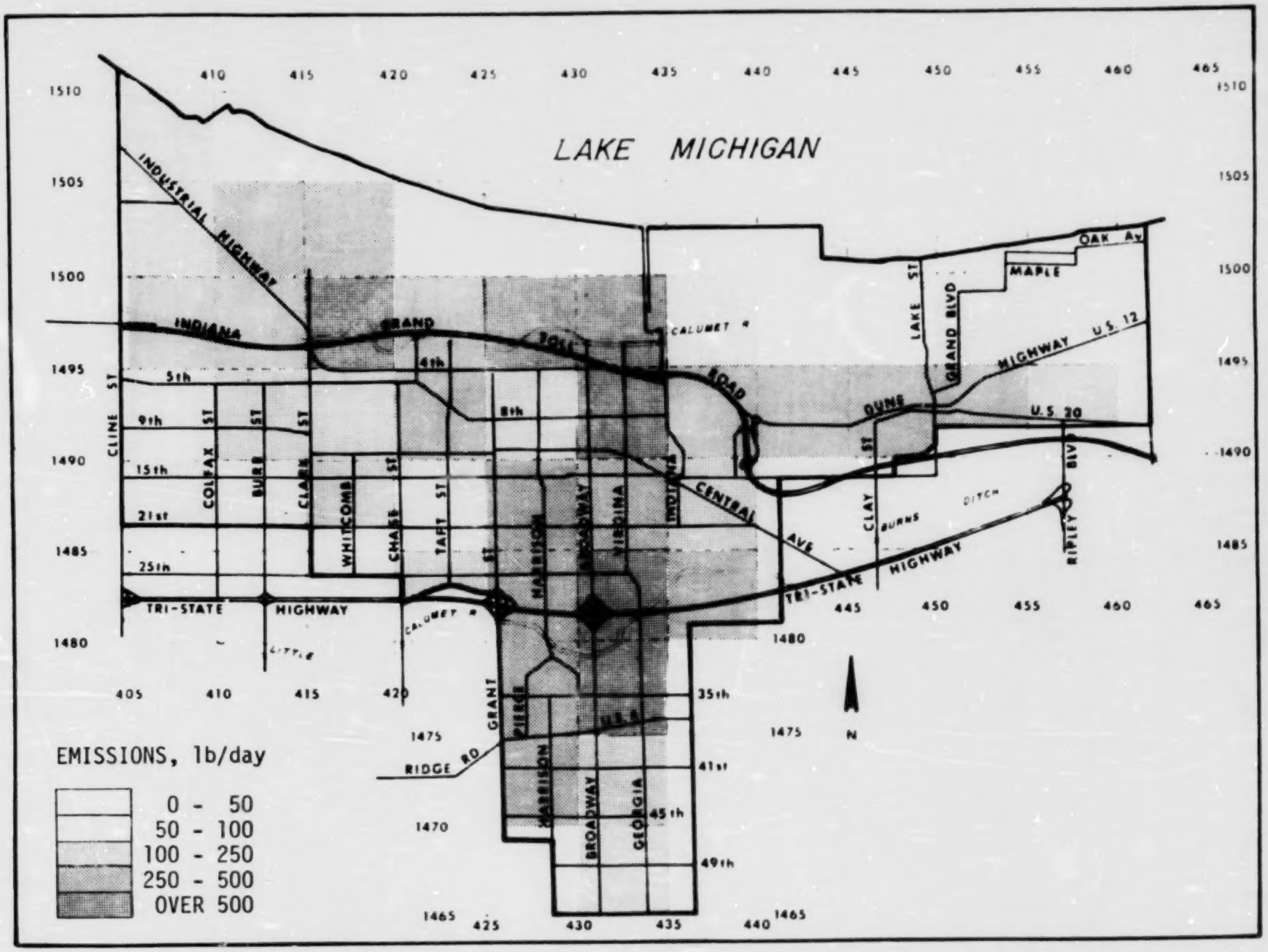

Figure 3. Oxides of nitrogen emitted by vehicles in Gary, Indiana

The combined emission rate of sulfur oxides and particulates is 2,640 pounds per day. If this pollution were distributed over the 41.6 square miles that comprise the land area of the City of Gary, the emission density for these two pollutants would be 63.5 pounds per square mile as compared to the emission density for carbon monoxide of 845.9 pounds per square mile.

Figure 4 illustrates the density of vehicle-miles traveled throughout the study area. This figure also indicates the locations at which the exhaust emissions will be vented to the atmosphere. The areas of heavy east-west traffic on the tri-state highway and the heavy north-south traffic on Broadway are also areas of heavy emissions. Figure 4 also indicates the areas of high-density traffic in the vicinity of the steel industry and in the downtown areas, where high-density emissions are found during specific hours of the day.

Figures 1, 2, and 3 illustrate the density of the different pollutants. Although the scales vary, these maps can be used as a comparison with the map locating the vehicle-mile densities.

The vehicle-mile average-speed approach is presently the most accurate method for estimating the emissions from motor vehicle exhausts. The accuracy of the method is dependent upon the number of vehicle counts and the availability of average-speed information for individual streets in the area under consideration. To estimate the vehicle-miles traveled in the City of Gary, 27 traffic counts were used, along with estimates of vehicle counts from a traffic flow map prepared by Tec-Search, Inc. for its comprehensive plan for the City of Gary. This information gave good coverage of the street system in the City of Gary and allowed calculation of 95 percent of the vehicle-miles, which were estimated by using national average figures for urban driving and motor vehicle registration information.

The calculation of the emissions of nitrogen oxides is somewhat arbitrary because an average air-fuel ratio of 12.8 was used to determine the emission factor. Since vehicle counts include cars, trucks, buses, etc., the air-fuel ratio should be varied instead of being assumed constant; but detailed traffic information would be necessary to accomplish the use of a varying emission factor for nitrogen oxides.

As stated before, the total emission of sulfur oxides and particulates from

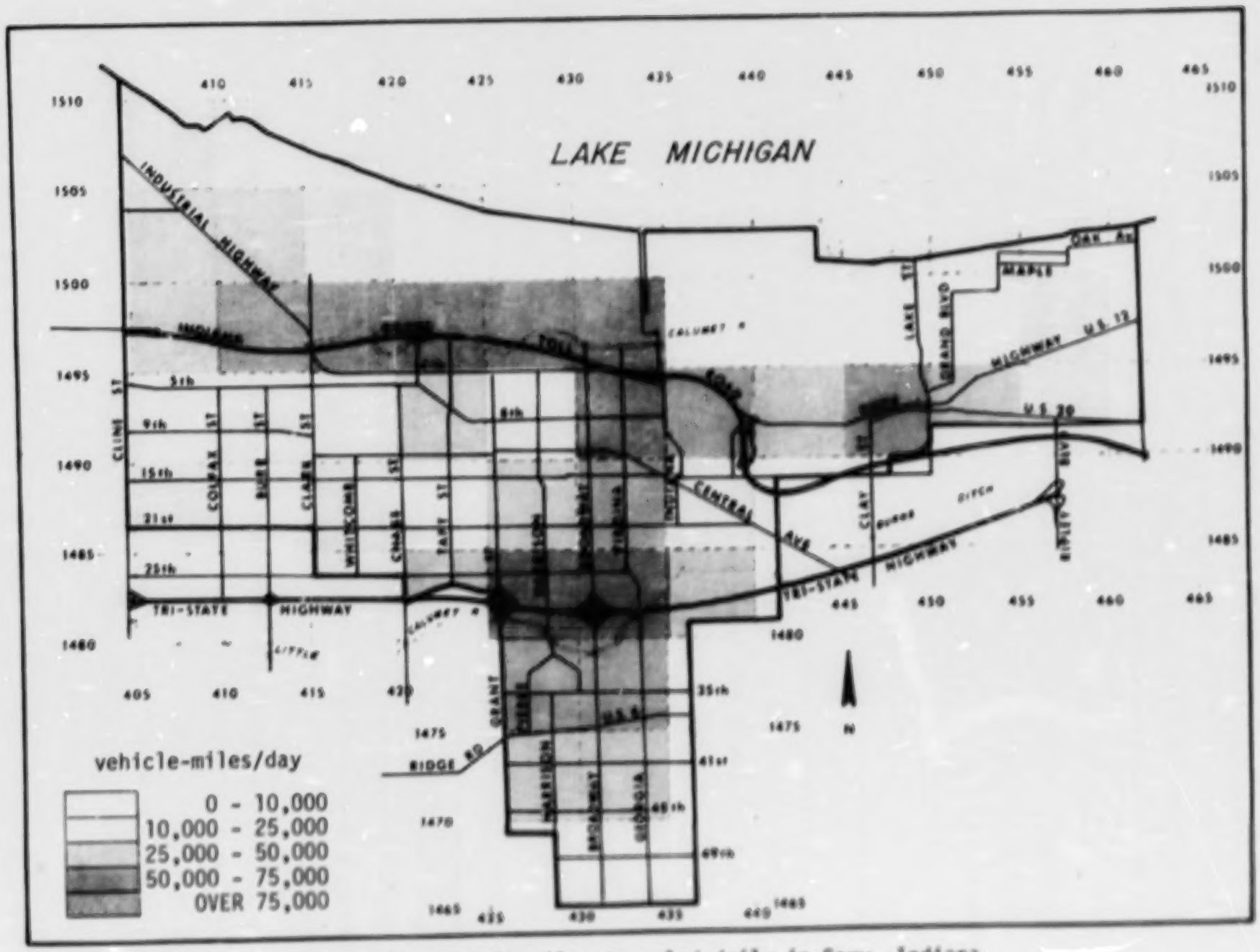

Figure 4. Vehicle-miles traveled daily in Gary, Indiana.

motor vehicles is small as compared with the three major pollutants. The use of the emission factors based on the fixed-mode cycle does not, therefore, introduce much error in the total weight of pollutants.

The concepts involved in this type of study are not complex in nature, and a detailed inventory of emissions from motor vehicles will enable a local agency to assess the importance of each pollutant within the total spectrum of emissions in a complex urban area.

PROCEDURE

Traffic Counts

The accuracy of the vehicle-mile approach for the calculation of motor vehicle exhaust emissions depends upon the number of vehicle counts (annual average daily traffic counts*) available for the street system of the city in question. The traffic counts used in this study were acquired from the following sources:

1. City of Gary Traffic Engineering Office
   a. Traffic counts on major streets (unpublished).
   b. A Highway Transportation Plan for the City of Gary, prepared by George W. Barton and Associates for the City of Gary, 1958.
2. Comprehensive Plan, The City of Gary, Indiana, 1964, prepared for the Gary Plan Commission by Tec-Search, Inc.
3. Indiana State Highway Department
   a. 1962 traffic map, Division of Planning, Indiana State Highway Commission.
   b. State Highway Commission, Planning and Statistics Engineering Department, provided individual traffic counts.

Figure 5 illustrates the locations and volumes of traffic on the major arterial streets in the City of Gary.

Street Mileage

The street mileage must be measured to complete the calculation of the vehicle-miles that are traveled in an area. The grid system used in the Northwest Indiana Air Resource Management Program was overlaid on the existing

*Annual average daily traffic counts are average counts taken throughout the year to reflect the numerous factors peculiar to that location, such as season, day of week, and time of day.

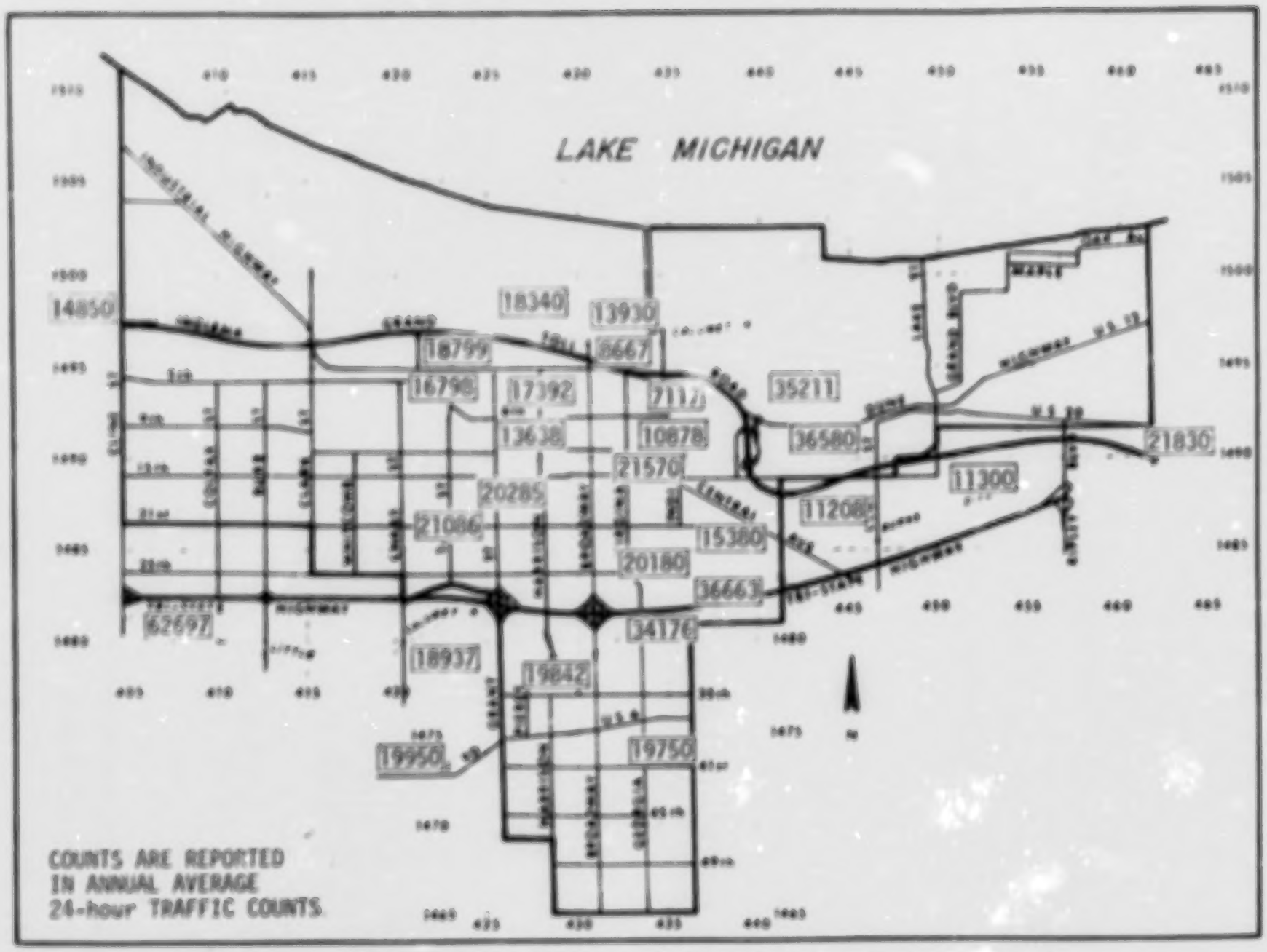

Figure 5. Traffic counts in Gary, Indiana.

land-use map of the City of Gary. The street mileage was measured and recorded by different land usage for each grid. The categories of land usage are:

1. Residential.
   a. single dwelling.
   b. multiple dwelling.
2. Commercial.
3. Industrial.
4. Other (including vacant lands, parks, agricultural lands, etc.).

The major streets, where traffic counts were available, were considered individually, and their mileage was recorded for each grid.

Vehicle-Mile Computation

The computation of the vehicle-miles for the City of Gary was done by taking the mileage in each land-use category and multiplying it by the vehicle count for the particular street. The estimated vehicle counts in Table 2 were used for the particulate land-use categories. Since a comprehensive traffic study was not available, these counts were used to complete the void of information. The validity of these counts should be investigated by the local officials along with the traffic engineering office.

Table 2. ESTIMATED VEHICLE COUNTS BY LAND-USE CATEGORY

Type	Count, vehicles/day
Major streets	17,000
Industrial	14,000
Commercial	10,000
Residential - Single dwelling	500
Multiple dwelling	1,000
Other	1,000

An example of the calculation under the following conditions is:

Grid number: 1495-410 Street: Residential

Street mileage: 4.0 Vehicle Count: 500 vehicles/day

Vehicle-miles = 500 (4.0) = 2,000 vehicle-miles/day.

The vehicle-miles calculated for the City of Gary totaled 1,639,523 vehicle-miles/day. This total was validated through the use of the following national average driving characteristics,[5] developed by the U.S. Bureau of Highways, for an

average vehicle traveling in an urban area.

1. Average speed = 25 miles/hour
2. Time required for trip = 19.2 minutes.
3. Trips per day = 3.25
4. Length of trips = 8.0 - 8.5 miles.

By applying these figures to the passenger car registration in the City of Gary for 1966, the calculated figure of vehicle-miles for the city of Gary appears very reasonable.

Check of Calculated Vehicle-Miles

1. Total calculated vehicle-miles = 1,639,523.
2. 1966 passenger car registration for the City of Gary = 66,550.
3. Average miles traveled per day = 3.25 trips x 8 miles = 26 miles/day.
4. Local vehicle-miles = 26 x 66,550 = 1,730,300 vehicle-miles.

Comparison of the calculated 1,639,523 vehicle-miles versus the estimated 1,730,300 vehicle-miles shows that the vehicle-mile approach obtained reasonable results for the study area in question.

Route Speed

The emission factors that are applied to the vehicle-miles traveled in an area are determined from the average speed for a prescribed trip on a certain street. Since actual route-speed surveys were not available, typical average route speeds were used. These speeds were determined by extensive testing. The values used and their respective land-use categories are listed below.

Street type	Average route speed, mph	Land-use category
Business	10	Commercial, industrial
Residential	16	Residential; single, multiple
Arterial	24	Major arterial streets
Average	25	Other
Freeway	45	Interstate highway

Emission Factors

Figures 6 and 7 illustrate the relationship between exhaust emissions and average trip or route speed. These curves were developed for carbon monoxide and hydrocarbons, two of the major pollutants from motor vehicles. The curves were used with the individual route speeds to obtain an emission factor for each of the pollutants. These factors (pounds of pollutant per vehicle-mile) were

applied to the vehicle-miles traveled on each street or type of street, and the resultant emissions were obtained.

An example of the procedure for calculating the emissions for grid number 1495-410 is given in Table 3.

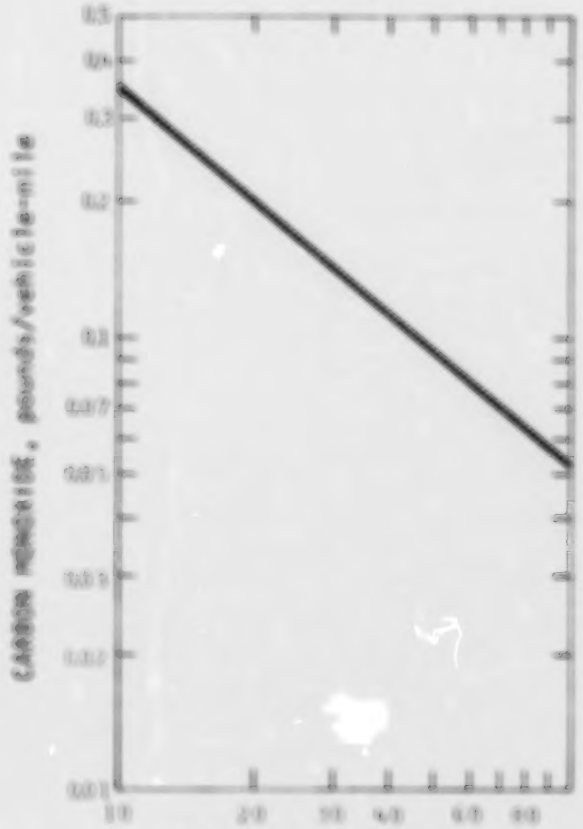

Figure 6. Exhaust emission of carbon monoxide per mile versus average trip speed.

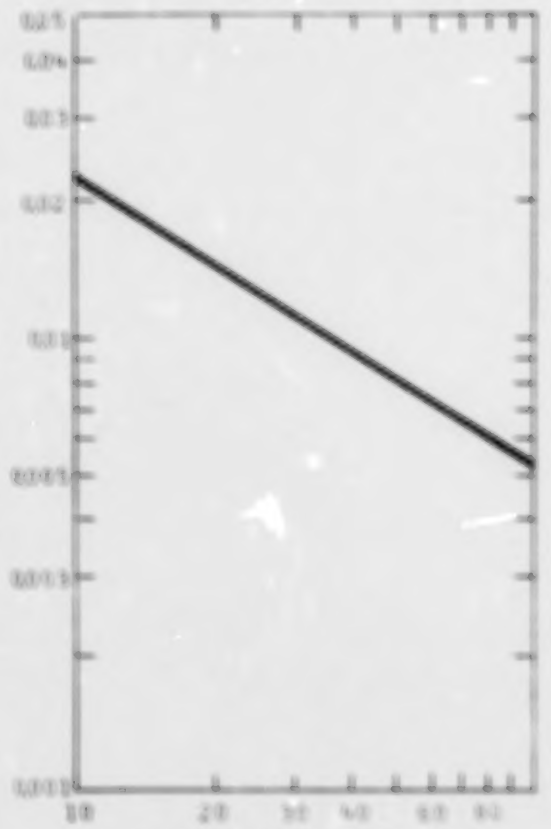

Figure 7. Exhaust emission of gross hydrocarbons (FIA) per mile versus average trip speed.

Table 3. CALCULATION OF CARBON MONOXIDE EMISSIONS FROM GRID 1495-410

Type of street	Vehicle count	Street mileage	Vehicle-miles/day	Route speed, mph	CO emission factor[a]	CO emissions, lb/day
Indiana toll rd.	14,000	1.0	14,000	45	0.013	1,442
5th Avenue	20,000	0.94	18,750	24	0.165	3,094
Industrial hwy.	25,000	0.38	9,375	24	0.165	1,547
Commercial	--	--	--	--	--	--
Residential	500	4.0	2,000	18	0.215	430
Other	--	--	--	--	--	--
Total			44,125			6,513

[a]Pounds per vehicle-mile.

The emissions of sulfur oxides and particulates from motor vehicles are not based on average route speed or the vehicle-mile approach. An estimation of the fuel consumed in the City of Gary was made so that emission factors based on pounds of pollutants emitted per 1,000 gallons of fuel consumed could be used.

The emissions of nitrogen oxides from motor vehicle exhausts are independent of speed, but they have been found to vary with the air-fuel ratio. Figure 8 illustrates this relation and designates the air-fuel ratio of 12.8 used in calculating the emissions from motor vehicles in the City of Gary.

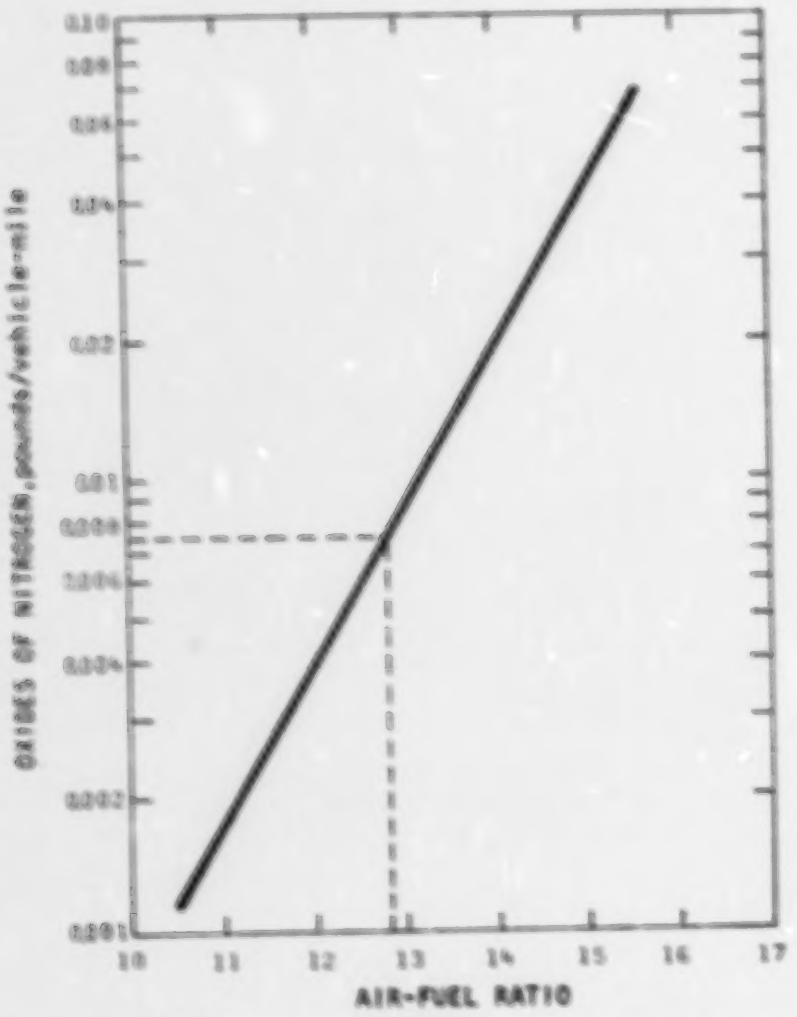

Figure 8. Exhaust emission of nitrogen versus air-fuel ratio.

According to published figures,[3] the average distance traveled per gallon of fuel consumed is 12.44 miles for all motor vehicles. This factor was applied to the calculated vehicle-miles, and an average figure of 131,800 gallons of fuel per day was estimated to be consumed in the Gary city limits. Service station sales

were converted to gallons of gasoline sold in the area as a check of the vehicle-mile approach for fuel consumption. An average figure for gasoline consumed per year on a national average was also used to check the gasoline consumption figures. The results are as follows:

1. Vehicle-Mile Approach.

   1,639,523 vehicle-miles/12.44 miles/gallon = 131,794 gallons/day

   Estimate of gasoline consumption in the City of Gary. (131,794 gal/day) (365 days/yr) = 48,104,810 gal/yr

2. Service Station Sales.[4]

Sales in Gary, Indiana	$ 18,459,000
Sales in State of Indiana	$492,251,000
Gasoline sold in State of Indiana	1,864,945,000 gal

   Estimate of gasoline sold in Gary, Indiana

   $$\frac{(\$18.5 \times 10^6)}{(\$492.3 \times 10^6)} \ (1.86 \times 10^9 \text{ gal}) = 69,513,000 \text{ gal/yr.}$$

3. National Averages.

Auto registration, City of Gary	66,550 cars
Truck registration, City of Gary	6,542

   National averages[3]

   Fuel consumption

   Cars (654 gal/car/year) (66,550 cars) = 43,523,700 gal/yr

   Trucks (1,350 gal/truck/year) (6,542 trucks) = 8,831,700 gal/yr.

   Estimated consumption of gasoline in the City of Gary

Since service station sales represent more than just gasoline consumption and since not all of the gasoline used in a year by each motor vehicle is consumed in the city limits, the lower estimate of 48 million gallons of gasoline was used in calculating the emissions of sulfur oxides and particulates. If the gasoline consumption determined from the national average figures (52,355,400) was used and 9 percent of the gasoline was assumed to have been consumed outside of the Gary area, the total consumption in the city would also be about 48.1 million gallons.

The emission factors for sulfur oxides and particulates were applied to the 131,800 gallons/day fuel consumption figure. Factors of 9 pounds of sulfur oxides and 11 pounds of particulates per 1000 gallons of gasoline consumed [6] were used

to calculate the amount of each pollutant that was emitted in the City of Gary on a daily basis. This quantity was then distributed to each grid zone by using a percentage of the vehicle-miles traveled in that grid to the total vehicle-miles traveled in the City of Gary.

To complete the inventory of major pollutants, an estimate of the amount of hydrocarbons emitted from crankcase and evaporative losses will be calculated. The emission factors for hydrocarbons are listed below:

Source	Emission factor,[2] lb/vehicle day
Evaporative losses	0.159
Crankcase losses	0.216
Total	0.375

To utilize this information, the vehicle-day must be related to the vehicle-mile. A vehicle-day is defined as the average use of a motor vehicle for one day. Utilizing the national average driving characteristics,[3] a vehicle-day can be defined as a vehicle making 3.25 trips of 8.0 mile length per day or a vehicle-day is equal to 26 vehicle-miles. The study area has an estimated 1,639,523 vehicle-miles traveled daily. This is equal to an estimated 63,058 vehicle-days. Applying the factors listed above, this would amount to 23,650 pounds of hydrocarbons on a daily basis and 4,316 tons of hydrocarbons on an annual basis over the study area. Evaporative losses account for 42.2 percent of this total while crankcase emissions account for 57.6 percent of the total.

MOTOR VEHICLE EMISSION INVENTORY PROCEDURES

The following outline is a summary of the procedure for calculating emissions from motor vehicles using the vehicle-mile approach.

I. Acquisition of Basic Data

  A. Type of data needed to complete survey

    1. Vehicle counts
    2. Traffic-flow maps
    3. Average route speeds
    4. Type of vehicle traveling area
    5. Vehicle registration
    6. Gasoline and diesel fuel consumption

7. Highway and local street maps
8. Land-use maps

B. Locations where data are available

1. Local traffic engineering office or city road department
2. Local police department
3. Local planning agencies
4. County facilities, same as 1. and 3.
5. State highway and traffic engineering offices
6. State motor vehicle registr tion office
7. State police department
8. Toll road commissions
9. Published data

II. Calculation of Pollutants

A. Calculation of Vehicle-miles

1. Overlay a grid system on a road map or land-use map.
2. Locate vehicle counts on map.
3. Measure individual streets where counts are available, and record the miles of each of these particular streets in each grid zone. (Do this by individual street.)
4. Record the specific traffic count by grid for each of the streets in step 3.
5. Using land-use map, locate and measure the remaining streets by land-use category, and record the miles of each category by grid. Record the vehicle count for each land-use by using either counts suggested by the local officials or those counts found in this text.
6. Calculate the vehicle-miles by multiplying the vehicle counts for each street or type of street and sum the individual vehicle-miles to a total for the area.
7. Check the total vehicle-mile figure with local traffic department estimate or with national figures. Go back and readjust if necessary.

B. Calculation of Emissions

1. Record average route speeds (time that it takes to go from one point to another including all stops) for individual streets and for each land-use category.
2. Using the average route speed, record the appropriate emission factor for each pollutant from the curves of emission rates versus average route (trip) speed for each street or category of streets.
3. Apply the emission factors (pounds per vehicle-mile) to the vehicle-miles for each street or category of streets in each grid and record the amounts of each pollutant.
4. Calculate the percent of vehicle-miles in each grid to the total vehicle-miles for the area in question, and record for each grid.
5. Estimate the gasoline and diesel oil consumed in the area in question and apply the emission factors for sulfur oxides and particulates, which are based on pounds of pollutants emitted per 1,000 gallons of gasoline or diesel fuel consumed, and sum the totals for the area.
6. Distribute the sulfur oxide and particulate totals by applying the percent of vehicle-miles traveled in the particular grid to the totals of each of these two pollutants.
7. Summarize each grid, and report results as desired.

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APPENDIX

EMISSIONS FROM MOTOR VEHICLES IN CITY OF GARY, INDIANA

Grid number	Vehicle-miles per day	Air pollution emissions, lb/day: Carbon monoxide	Hydro-carbons	Nitrogen oxides	Sulfur oxides	Partic-ulates
1485-405	10,000	2,529	173	74	7	9
1490-405	8,000	1,320	100	60	6	7
1495-405	48,013	7,050	547	359	35	42
1500-405	33,125	8,216	2,236	249	24	29
1505-405	21,875	3,610	273	164	16	19
1485-410	8,375	1,813	131	63	6	7
1490-410	21,250	8,489	611	159	15	19
1495-410	57,031	8,560	661	428	41	50
1500-410	25,000	4,125	313	188	18	22
1485-415	21,500	4,894	349	162	16	19
1490-415	17,625	4,476	310	132	13	16
1495-415	67,887	12,204	900	509	49	60
1500-415	17,000	4,250	298	128	12	15
1480-420	40,550	5,616	433	305	29	36
1485-420	9,000	1,848	135	68	7	8
1490-420	41,625	11,192	766	312	30	37
1495-420	78,380	14,324	1,055	481	57	69
1465-425	1,500	298	22	12	1	1
1470-425	27,625	5,643	415	210	20	24
1475-425	56,150	16,556	1,100	422	41	50
1480-425	81,009	12,857	920	492	59	72
1485-425	46,330	11,245	782	347	34	41
1490-425	16,250	4,914	326	122	12	14
1495-425	102,652	22,638	1,649	871	74	91
1465-430	12,656	2,600	188	95	9	11
1470-430	26,500	4,253	452	199	19	23
1475-430	72,013	22,298	1,471	540	52	64
1480-430	75,496	13,405	959	566	55	67
1485-430	59,171	19,204	1,254	444	43	52
1490-430	100,525	33,100	2,099	750	73	89

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EMISSIONS FROM MOTOR VEHICLES
IN CITY OF GARY, INDIANA
(continued)

Grid number	Vehicle-miles per day	Carbon monoxide	Hydro-carbons	Nitrogen oxides	Sulfur oxides	Partic-ulates
1495-430	96,624	15,072	1,070	505	70	85
1465-435	3,125	547	41	24	2	3
1470-435	875	168	14	66	1	1
1475-435	4,250	802	59	32	3	4
1480-435	38,660	4,106	344	290	28	34
1485-435	14,950	2,924	213	102	11	13
1490-435	61,000	11,076	819	458	44	54
1495-435	7,500	773	65	56	5	7
1480-440	9,165	944	80	68	7	8
1485-440	6,677	1,002	77	50	5	6
1490-440	42,580	8,747	628	319	21	38
1490-445	55,595	11,359	811	417	40	49
1495-445	6,000	1,797	119	85	4	5
1500-445	563	121	9	4	--	--
1490-450	37,625	8,659	607	282	27	33
1495-450	8,750	1,788	130	66	6	8
1500-450	1,375	295	21	10	1	2
1490-455	14,963	2,993	217	112	11	13
1495-455	12,125	2,457	178	91	9	11
1500-455	4,000	860	62	30	3	3
1490-460	4,375	883	64	33	3	4
1495-460	3,000	583	42	23	2	3
1500-460	1,625	349	25	12	1	1
Grid totals	1,639,523	351,848	26,627	11,947	1,188	1,452